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BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: LM Descent Profiles with Steep Final Approach Phases - Case 310

DATE: March 17, 1969

FROM: F. Heap
V. S. Mummert

ABSTRACT

Despite many minor changes in guidance and targeting parameters, the major features of the LM powered descent for the lunar landing mission have remained essentially unchanged for many years. A major feature of this profile is the shallow approach path which provides relatively low altitude rates during the final approach phase and relatively low redesignation delta-V costs. Two very undesirable features of the shallow approach are the narrow range of lunar lighting conditions which provide acceptable visibility and the high vehicle attitude sensitivity to the uprange terrain profile. This memorandum parametrically examines a class of "steep descent" trajectories proposed for lunar exploration missions for which acceptable pilot visibility may be required over a wider range of lighting conditions and for which the lunar approach terrain will be more irregular than for the first lunar landing. It is shown that a steep descent trajectory having a -45° flight path angle from high gate to low gate incurs a delta-V penalty of about 280 fps as compared to the present profile. However, landing radar updates would begin about 16 n.m. uprange rather than 30 n.m. and landing with solar elevations as high as 40° will result in no photometric washout. (Washout occurs at about 16° on the present profile.)

In addition it is suggested that the delta-V penalty inherent in steep descents can be absorbed by modifications to other aspects of the descent profile such as reduced lunar orbit altitude, reduced throttle down time, and reduced time in the final approach and landing phases. If all of these modifications can be implemented as suggested, the nominal LM descent delta-V budget for the proposed profile will be about 200 fps less than that of the present profile.

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MEMORANDUM FOR FILE

I INTRODUCTION

Despite the many minor changes that have been made in guidance mechanization, engine operation, and certain trajectory parameters, the major features of the LM powered descent trajectory for the lunar landing mission have remained essentially unchanged for many years. After ignition near perilune (at an altitude of 50,000 feet) on the Hohmann transfer orbit, a fuel optimum profile is flown to an altitude of about 9,600 feet. The major reduction in velocity takes place during this phase. The terminal target state vector for the braking phase is known as "high gate". At high gate the LM is pitched to a non-optimum attitude which will provide visibility of the planned landing site for the crew. The vehicle is then flown in an attitude designed to provide adequate visibility throughout this "final approach" phase to the "low gate" target point. The "landing" phase follows.

One major feature of the present profile is the relatively shallow approach path; the flight path angle in the final approach (or visibility) phase has traditionally been in the range -15 to -18 degrees. The advantages of a shallow approach are that the altitude rates during the final approach phase are quite low and the cost of redesignation early in this phase is low because the total velocity is high. One disadvantage of a shallow approach is that the landing radar becomes effective at a large distance from touchdown; if the altitude of the uprange terrain is much different from that at touchdown, the relative altitude information fed into the guidance system is incorrect. In addition, if the terrain is rough, the pitch oscillations resulting from radar altitude updates may cause radar dropout. In particular,the long, low glide path during the final approach phase requires a relatively long (over 30,000 feet), smooth approach path to the lunar landing site in order to avoid unwanted pitch oscillations during this visibility phase. A second major disadvantage of the shallow final approach is that visibility is poor except for a very narrow range of lighting conditions. For solar elevations above 12°, photometric scene washout becomes a constraint on the mission (Reference 5).

This memorandum examines a class of LM descent profiles which possess short, steep final approach phases. They would considerably improve the lunar visibility conditions during the final approach phase and reduce requirements on the terrain uprange of the landing site. The profiles are examined as candidates for landings during Apollo lunar exploration missions, and the LM vehicle models and initial CSM orbit reflect assumptions consistent with those missions (Reference 4). A CSM orbital altitude of 50,000 feet, a final approach phase of about 120 seconds, and a throttle down interval prior to high gate of 60 seconds are assumed.

Section II deals with a series of trajectory calculations performed to explore the effects of steeper descents. In these calculations, the final approach phase flight path angle and look angle (angle between the LM thrust axis and the line of sight to the aim point) were kept constant. This constrains the vehicle acceleration vector (pitch angle and thrust acceleration magnitude) to be constant also. Time of flight and flight path angle in the final approach phase (from high gate to low gate) were varied to parametrically determine the delta-V costs and the required high gate altitudes for a class of steep descent profiles.

Since the proposed profile for lunar exploration differs from the standard in many respects other than final approach flight path angle, a further series of trajectory simulations was made in which the effects on the descent delta-V of individual, discrete changes in a number of the descent parameters such as throttle down time, orbit altitude, etc., were determined. The purpose was to evaluate the delta-V cost of each of the trajectory changes in going from a standard trajectory to the proposed steep descent trajectory. These sensitivities are reported in Section III.

In Section IV, the parametric results of Sections II and III are used to synthesize a particular steep descent targeting which is then compared with a standard Apollo powered descent trajectory (Reference 1).

II PARAMETRIC STUDY OF STEEP DESCENTS

The steep descent trajectories examined are characterized by having essentially constant flight path angles and constant look angles to the hover aim point in the final approach phase. The final approach geometry is illustrated in Figure 1. The hover aim condition was chosen to be: altitude 50 feet, horizontal velocity and vertical velocity zero. No constraint was placed on the LM attitude at the aim point. For constant flight path angle and constant look angle, the thrust acceleration vector must also be constant (for a flat, non-rotating moon approximation). Thus, for a given flight path angle and time of flight in the final approach phase, high gate starting conditions (altitude, range and velocity) can be easily computed by simple quadrature, as shown on Figure 1 and described below.

Because the flight path from high gate to low gate must be rectilinear, the forces orthogonal to the flight path must be null; the required thrust acceleration profile is then calculated as

$$T/M \sin \lambda = g \cos \gamma, \text{ or}$$

$$T/M = a_t = g \cos \gamma / \sin \lambda .$$

where

T	=	vehicle thrust profile
M	=	vehicle mass as a function of time
a_t	=	vehicle thrust acceleration (constant)
g	=	lunar gravity
γ	=	flight path angle measured negative down from the local horizontal (constant)
λ	=	look angle from negative x-axis (thrust axis) to hover aim point (constant)

The acceleration along the flight path is also constant and is calculated as

$$\dot{v} = -g \sin \gamma - T/M \cos \lambda .$$

The high gate velocity is

$$V_o = -\dot{v}\, t_f ,$$

where t_f = desired flight time from high gate to low gate.

The components of high gate velocity, $\dot{R}_o$ or range rate and $\dot{h}_o$ or altitude rate, are

$$\dot{R}_o = V_o \cos \gamma, \text{ and}$$

$$\dot{h}_o = V_o \sin \gamma .$$

The rectilinear distance from high gate to low gate is calculated as the second integral of acceleration,

$$S_o = -1/2\ \dot{v}t_f^2.$$

The range and altitude of high gate can then be determined as

$$R_o = S_o \cos \gamma, \text{ and}$$

$$h_o = -S_o \sin \gamma + h_f.$$

where h_f = altitude of low gate = 50 ft.

R_o, h_o, $\dot{R}_o$, and $\dot{h}_o$ then completely specify the high gate target conditions as a function of low gate targets, time of flight, flight path angle, and look angle.

To determine the total delta-V requirements for the complete descent from parking orbit to touchdown, together with the flight profile and other relevant data, trajectory simulations were made using the targeting mode of the Bellcomm Apollo Simulation Program (BCMASP) for each of the high gate conditions of Table I. The time in the final approach phase was varied from 60 seconds to 120 seconds for flight path angles ranging from -10° to -45°. The LM was assumed to start from a 50,000 foot circular orbit (Reference 4). The starting weight of the LM was assumed to be 33,600 lbs. (excluding crew and transferred equipment). Throttle recovery was achieved 60 seconds before high gate (assumes a DPS throttling capability about the FTP). Discrete transition phases at high gate and hover were not included. The look angle (the angle between the line of sight to the hover aim point and the negative x-axis as shown on Figure 1) was 35 degrees for these simulations. Since the bottom of the LM window occludes viewing within 25 degrees of the negative x-axis, the aim point will appear 10 degrees above the window bottom at the start of final approach, with loss of visibility of the touchdown point typically occurring about 30 seconds before touchdown. This angle between the window bottom and the line of sight to the aim point is referred to as the visibility angle.

The altitude at high gate and the total delta-V are shown in Figure 2 as a function of flight path angle and flight time in the final approach phase. From this figure it is apparent that steep descent trajectories have higher delta-V requirements. Increasing the flight path angle from -15° to -45° raises delta-V requirements by about 280 fps for a final approach phase of 120 seconds duration. It is also seen that high gate altitude maximizes at a flight path angle of about -28° for all flight times considered.

III SENSITIVITIES TO DESCENT PARAMETER CHANGES

In order to design a lunar exploration LM descent profile which accommodates a steep descent final approach phase with delta-V requirements equal to or less than current requirements, it is necessary to understand how much each trajectory parameter is responsible for contributions to the total delta-V requirements. To aid in this understanding a series of BCMASP descent simulations was made in which one parameter was altered in each run to progress from a reference trajectory (similar to that contained in Reference 1) to the steep descent trajectories. For completeness, the regression from this reference trajectory to a previous reference trajectory (similar to that contained in Reference 2) was also made on an item-by-item basis. The results are shown in Table II. The increment in delta-V ($\delta(\Delta V)$) shown for each case is from the adjacent run in the series, reading up and down from the reference trajectory.* It is seen that the steep descent "costs" almost 200 fps for a 35° flight path angle, that the 50,000 foot initial orbit saves 140 fps, and that reducing the throttle down time prior to high gate by 60 seconds saves about 50 fps. The latter saving probably requires improved navigation prior to high gate or some engine throttling capability about the fixed throttle point. The combined effect of a 10° visibility angle above the LM window bottom and a 2 minute final approach phase results in a potential saving in excess of 220 fps.

IV COMPARISON WITH STANDARD APOLLO LM DESCENT

Based on the parametric analysis of Sections II and III, a single steep descent profile was chosen for detailed analysis and comparison with an existing Apollo reference profile as described in Reference 1. The major characteristics of these trajectories are set out below.

Parameter	Apollo Profile (Ref 1)	Proposed Steep Profile
Altitude of CSM orbit	60 n.m.	50,000 ft.
Initiation of powered descent	50,000 ft.	50,000 ft.
Nominal throttle down period prior to high gate	117 sec.	60 sec.

*The numbers shown in Table II for the reference trajectory are from the BCMASP simulation, using high gate aim conditions and final approach characteristics from Reference 1.

Parameter	Apollo Profile (Ref 1)	Proposed Steep Profile
Range of high gate	32,500 ft.	6,833 ft.
Flight path during final approach phase	$\sim$-16°	-45°
Altitude of high gate	9,650 ft.	6,935 ft.
Period site is visible	150 sec.	90 sec.
Visibility angle	7-23°	10°
Nominal delta-V requirement	6611 fps	6428 fps

Detailed comparison plots of range, altitude, altitude rate, flight path angle, pitch angle, and thrust as a function of time from ignition to high gate are shown in Figures 3a through 3f. The braking phase for the steep descent profile extends 17 seconds longer than for the reference profile (despite initiation from a 50,000 foot circular orbit) because of the reduced altitude and velocity at high gate. Figure 3b indicates that if landing radar updating is assumed to begin at an altitude of 25,000 feet, it would occur at about 325 seconds after ignition on the reference profile and 375 seconds on the proposed steep descent profile. Figure 3a then shows that the range-to-go at which updating begins is reduced from 30 miles to about 16 miles uprange. The advantages in terms of "smoothness" constraints on the uprange terrain are apparent. The throttle down point on the steep trajectory occurs about 60 seconds prior to high gate (Figure 3f) as opposed to 117 seconds on the reference. As pointed out in Section III, about 50 fps are thereby saved but a Descent Propulsion System modification to permit limited throttling about the fixed throttle point is probably required to realize this efficiency.

Individual trajectory parameters as a function of time to go to landing for the final approach and landing phases are compared on Figures 4a through 4i. Since the steep descent simulation contained no transition phase at high gate, its thrust and angular parameters will, in general, be discontinuous between Figures 3 and 4. As shown on Figure 4c, the rate of descent is about 50% greater on the proposed profile. Figure 4e shows the constant (-45°) flight path angle on the proposed profile. The pitch attitude also remains nearly constant on the proposed profile (Figure 4g). Figure 4f illustrates the variation of look angle to the landing site and visibility angle on these trajectories. The reference profile has a visibility angle (margin of look angle above LM window bottom) of about 7° at high gate growing almost linearly to 23° at low gate with dropout at about 10 seconds before touchdown. The steep descent profile initially has a visibility angle of 10°; dropout occurs at about 30 seconds before touchdown. Thus while the reference profile has about 150 seconds of visibility, this steep descent has but 90 seconds and the margin for pitch oscillations is considerably reduced. Higher margins on the visibility angle can be had at a delta-V penalty. As indicated on Table II, increasing visibility angle from 10° to 15° costs about 55 fps. The viewing angle, the angle from the local horizontal to the landing site, which is traditionally used in visibility studies such as Reference 4 can be calculated as

$$\text{View Angle} = 90° - \text{Look Angle} - \text{Pitch Angle} \quad \text{(from Figure 1)}$$

Since the look angle of Figure 4f is calculated with respect to the landing site (Figure 1 uses the hover aim point), viewing angle can be calculated directly from Figures 4f and 4g. The results, shown on Figure 4h, clearly illustrate the advantages of the steep descent relative to increased viewing angle. Photometric scene washout would be avoided for solar elevations as high at 40°; the range of acceptable solar elevations is effectively limited only by the requirement for shadowing as a means of obstacle detection.

Another advantage accrues to the steep descent profile if lunar landings into the sun are considered for lunar exploration missions. As indicated in Reference 6, the primary glare source for landings against the sun is dazzle from sunlight directly in the pilot's eyes rather than scattered light from the LM windows. Since steep descent profiles have smaller pitch angles (measured from the local vertical) compared to the present profile, structural blocking of the sun from the pilot's eyes occurs over a broader range of sun angles. Reference 6 shows that pitch angles of 10°, which are typical of steep descent profiles, have excellent visibility conditions for sun elevations as low as 30° from the forward horizon. By way of contrast, an approach path similar to that of Reference 1 encounters serious dazzle problems at sun elevations of 60° from the forward horizon. Since scene contrast is higher at the lower elevations and lunar surface thermal conditions are more favorable, landing at the lower elevations results in an easier mission. Hence, the steep descent profile enhances the possibility of a mission opportunity with a landing into the sun either as a means to improve the visibility at the site or to expand the number of days in the monthly launch opportunity.

Figure 5 indicates the degree to which constraints imposed on early lunar landing missions (Reference 3) are violated by the proposed lunar exploration, steep descent profile. As would be expected, the altitude and altitude rate as a function of range to go greatly exceed the referenced constraints.

V. SUMMARY

After performing a parametric study of steep-descent trajectories, a reference profile has been chosen which has a -45° flight path angle from high gate to hover and a high gate altitude of about 7000 feet. The resulting flight time from high gate to hover is 110 seconds with a pitch angle of 10°. This profile satisfies follow-on lunar mission objectives in that it has a short range from high gate to touchdown and will result in considerably improved scene contrast during the final approach phase. The reduced high gate range (7000 feet contrasted to the 32,500 feet in a standard Apollo profile) reduces the terrain requirements on the landing site approach; the rougher uprange terrain expected for lunar exploration sites can be more easily accommodated without excessive pitch oscillations during the final approach or visibility phase.

The proposed steep descent profile has nominal delta-V requirements of 6428 fps as contrasted with 6611 fps for the standard Apollo profile. Steep descent trajectories inherently incur a delta-V penalty because they have higher gravity losses during the final approach phase. A -45° flight path during this phase costs about 280 fps more than the standard profile, but proposed modifications to the profile can compensate for this penalty. The proposed reductions come about because of a 50,000 foot CSM parking orbit (∿ 140 fps), reduced nominal throttle down time (∿ 50 fps), reduced visibility time (∿ 70 fps), and reduced margins on the look angle (∿ 160 fps). The latter reduction places increased emphasis on controlling LM pitch attitude during the final approach phase. Then, while steep descent trajectories are inherently more expensive than those with a shallow approach, a profile with reduced delta-V requirements can be synthesized by adjustments in other parameters.

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F. Heap

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V. S. Mummert

Attachments
  References
  Tables I and II
  Figures 1 through 5e

REFERENCES

1. LM Powered Descent Trajectory for the Apollo Lunar Landing Mission. J. H. Alphin, B. G. Taylor and B. G. Kirkland, MSC Internal Note 68-FM-78. March 29, 1968.

2. Proposed LM Powered Descent Trajectory for the Apollo Lunar Landing Missions. W. M. Bolt and F. V. Bennett, MSC Internal Note 67-FM-117. August 15, 1967.

3. Trajectory and Constraints for Final Approach and Landing Phases of LM Lunar Landing. MSC GCD Memorandum EG 27-4-66.

4. "Spacecraft Payload and Mission Profile Changes for Lunar Exploration Missions", D. R. Anselmo and J. L. Marshall, Jr., Bellcomm Memorandum for File, March 17, 1969.

5. "Evaluation of Lunar Lighting Constraint Based Upon Photometric Derived Scene Contrast", D. R. Anselmo and P. A. Cavedo, Bellcomm TM-66-2013-1, April 29, 1966.

6. "Reduction in Lunar Surface Visibility Due to Glare During a Landing into the Sun", R. Troester, Bellcomm TM-68-2013-5, September 30, 1968.

TABLE I

HIGH GATE CONDITIONS FOR STRAIGHT LINE
FINAL APPROACH DESCENTS

HOVER ALT : 50 FT
HOVER VELOCITY : 0
LOOK ANGLE TO AIM POINT 35° FROM NEG. X-AXIS

FLIGHT PATH ANGLE (DEG)	FINAL APPROACH PHASE TIME (SEC)	HIGH GATE ALT (FT)	HIGH GATE RANGE (FT)	HIGH GATE VELOC. (FT/SEC)	THRUST ACCEL-ERATION (FT/SEC^2)	PITCH ANGLE (DEG)
-10	60	2098	11615	393.1	9.125	45
-10	90	4658	26134	589.7	9.125	45
-10	120	8242	46460	786.3	9.125	45
-20	60	3322	8990	318.9	8.708	35
-20	90	7412	20227	478.4	8.708	35
-20	120	13138	35960	637.8	8.708	35
-30	60	3575	6105	235.0	8.025	25
-30	90	7980	13735	352.5	8.025	25
-30	120	14148	24419	469.9	8.025	25
-35	60	3322	4673	190.2	7.591	20
-35	90	7412	10514	285.2	7.591	20
-35	120	13138	18692	380.3	7.591	20
-40	60	2824	3307	143.9	7.098	15
-40	90	6294	7441	215.9	7.098	15
-40	120	11150	13228	287.8	7.098	15
-45	60	2098	2048	96.5	6.552	10
-45	90	4658	4608	144.8	6.552	10
-45	110	6934	6884	177.0	6.552	10
-45	120	8242	8192	193.1	6.552	10

TABLE II - EFFECTS OF SYSTEMATIC CHANGES IN LM DESCENT PARAMETERS

W_0 (LBS)	I_{SP} (SEC)	ORBIT ALT.	RECOVERY THRUST (LBS)	THROT. DOWN INT'V'L (SEC)	TRANS-ITION PHASES	FLT PATH ANGLE (DEG)	TIME FINAL APPRO. (SEC)	HOVER ALT. (FT)	VISIB. ANGLE (DEG)	ΔV DOI (FPS)	ΔV BRAK. (FPS)	ΔV VISIB. (FPS)	ΔV VER. DES. (FPS)	ΔV TOT (FPS)	δ(ΔV) (FPS)	REMARKS
-	-	80 NM	5250	117	YES	17-15	166	100	9-25	97	5362	1166	81	6706	-	PRIOR REFERENCE TRAJECTORY (REFERENCE 2)
32600	304	80 NM	5250	117	YES	16.5-15	166	100	9-25	97	5365	1161	88	6711	-	BCMASP SIMULATION OF REFERENCE 2
33324	304	80 NM	5460	117	YES	16.5-15	166	100	9-25	97	5367	1161	88	6713	0	INCREASE I_{SP} FROM 300.1 TO 304
33324	300.1	80 NM	5460	117	YES	16.5-15	166	100	9-25	97	5365	1160	89	6713	+53	INCREASE ORBIT ALTITUDE FROM 60 TO 80 NM
33324	300.1	60 NM	5460	117	YES	16.5-15	166	100	9-25	71	5340	1161	88	6660	+19	REDUCE RECOVERY THRUST FROM 57% TO 52%
33324	300.1	60 NM	5985	117	YES	16.5-15	166	100	9-25	71	5323	1159	88	6641	+30	ADD TRANSITION PHASES
33324	300.1	60 NM	5985	117	NO	16.5-15	158	100	7-23	71	5282	1157	101	6611	0	BASIC REFERENCE TRAJECTORY (REFERENCE 1) BCMASP SIM
33324	300.1	60 NM	5985	60	NO	16.5-15	158	100	7-23	71	5234	1156	101	6562	-49	DECREASE THROTTLE-DOWN TIME FROM 117 SEC TO 60 SEC
33324	300.1	50K FT	5985	60	NO	16.5-15	158	100	7-23	0	5165	1156	102	6423	-139	START FROM 50K FT CIRCULAR ORBIT
33324	300.1	50K FT	5985	60	NO	16	158	100	10	0	4746	1416	101	6263	-160	REDUCE VISIB. ANGLE TO 10°, (VIOLATES LANDING CONSTRAINTS OF REFERENCE 3)
33324	300.1	50K FT	5985	60	NO	16	120	100	10	0	5027	1066	101	6194	-69	REDUCE TIME IN FINAL APPROACH TO 120 SEC
33324	300.1	50K FT	5985	60	NO	16	120	100	15	0	5199	950	101	6250	+56	INCREASE VISIB ANGLE TO 15°
33324	300.1	50K FT	5985	60	NO	35	120	100	15	0	5538	806	102	6446	+196	INCREASE FLT PATH ANGLE TO 35°

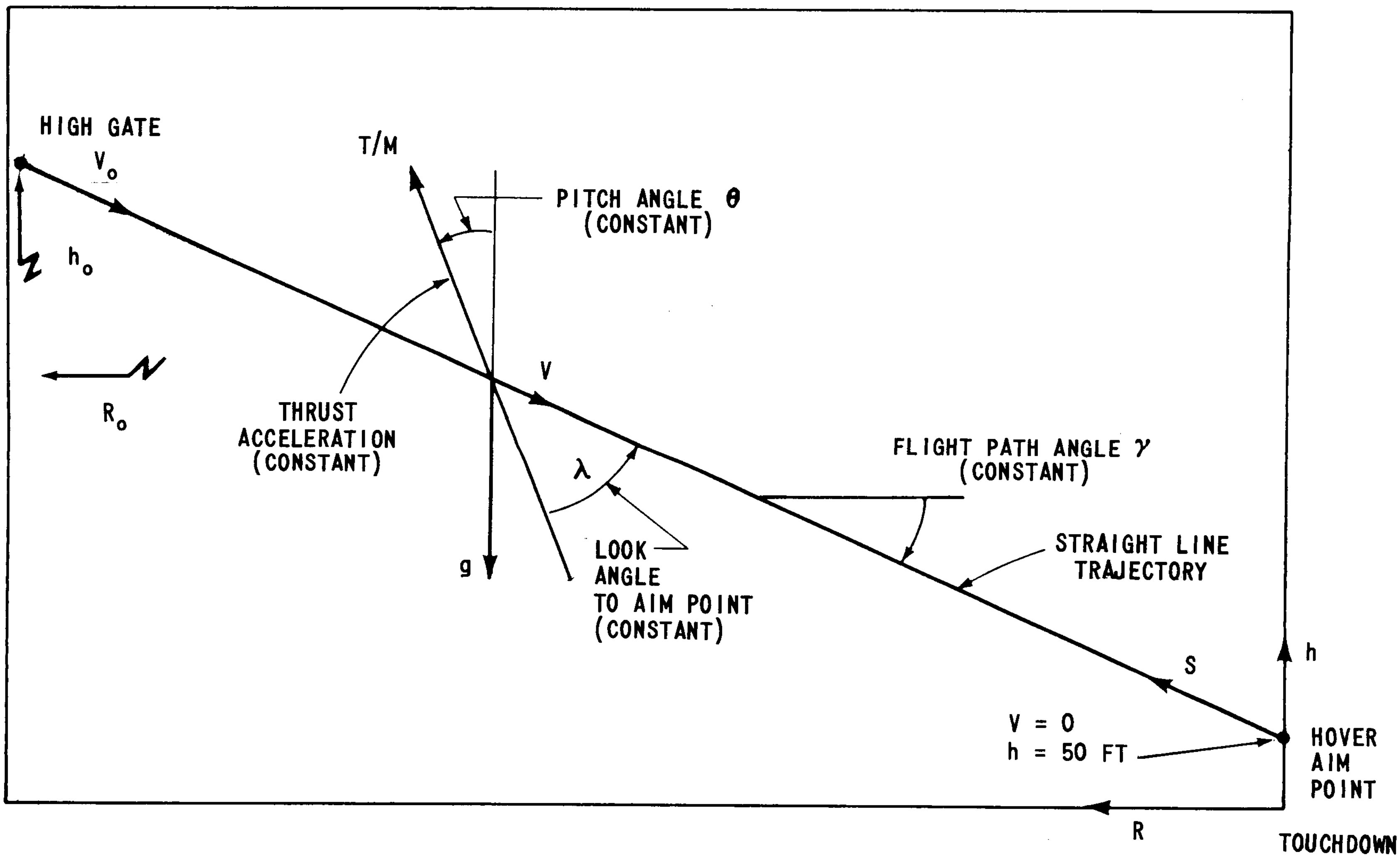

FIGURE 1 - STRAIGHT LINE FINAL APPROACH PHASE GEOMETRY

INITIAL WT 33,600 LB.
CONSTANT LOOK ANGLE 10 DEG ABOVE WINDOW BOTTOM
CONSTANT ACCELERATION IN FINAL APPROACH
HOVER AT 50 FT (VELOCITY = 0)
INITIAL 50,000 FT CIRCULAR ORBIT

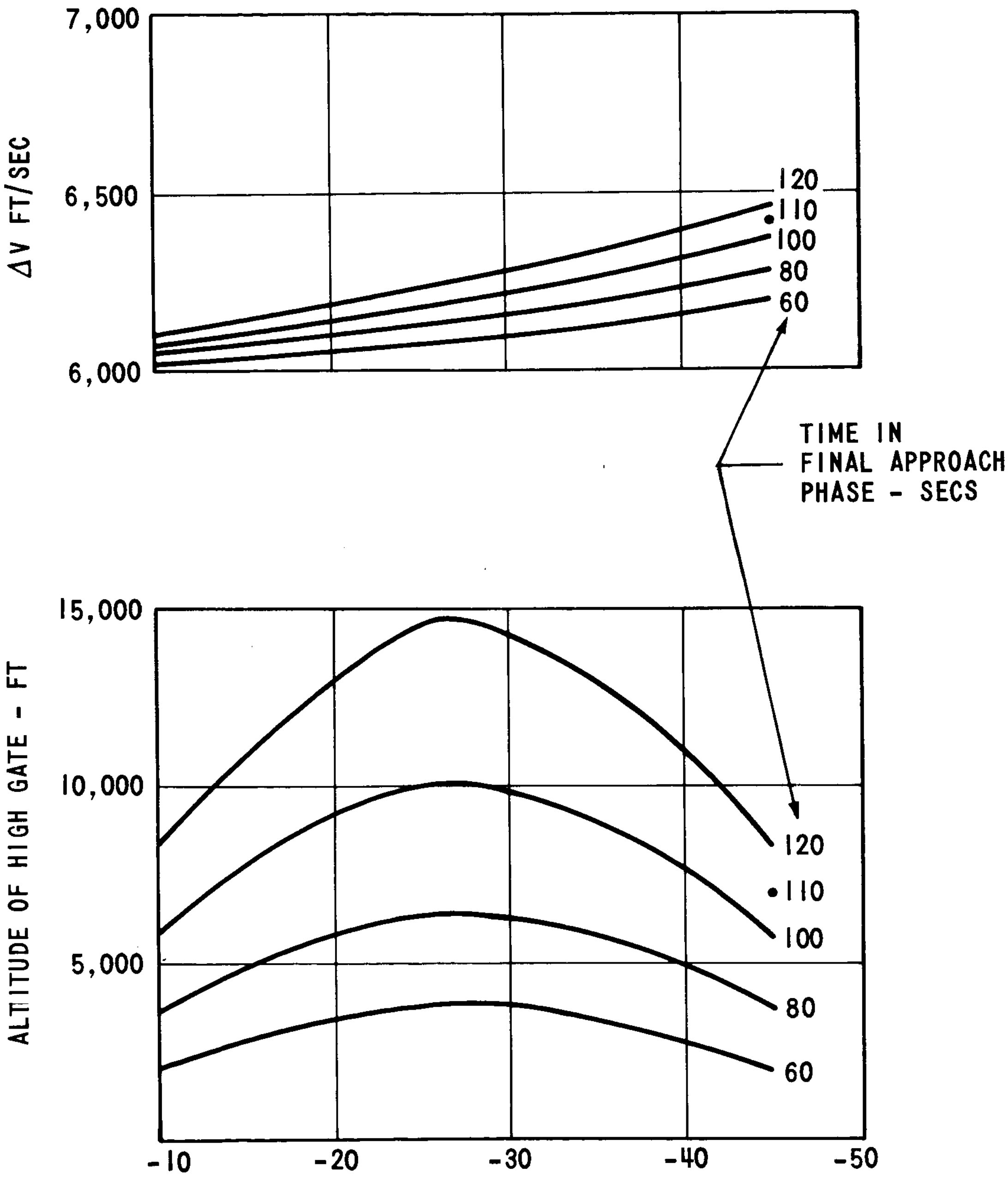

FIGURE 2 - HIGH GATE ALTITUDE AND TOTAL ΔV REQUIREMENTS AS A FUNCTION OF FINAL APPROACH FLIGHT PATH

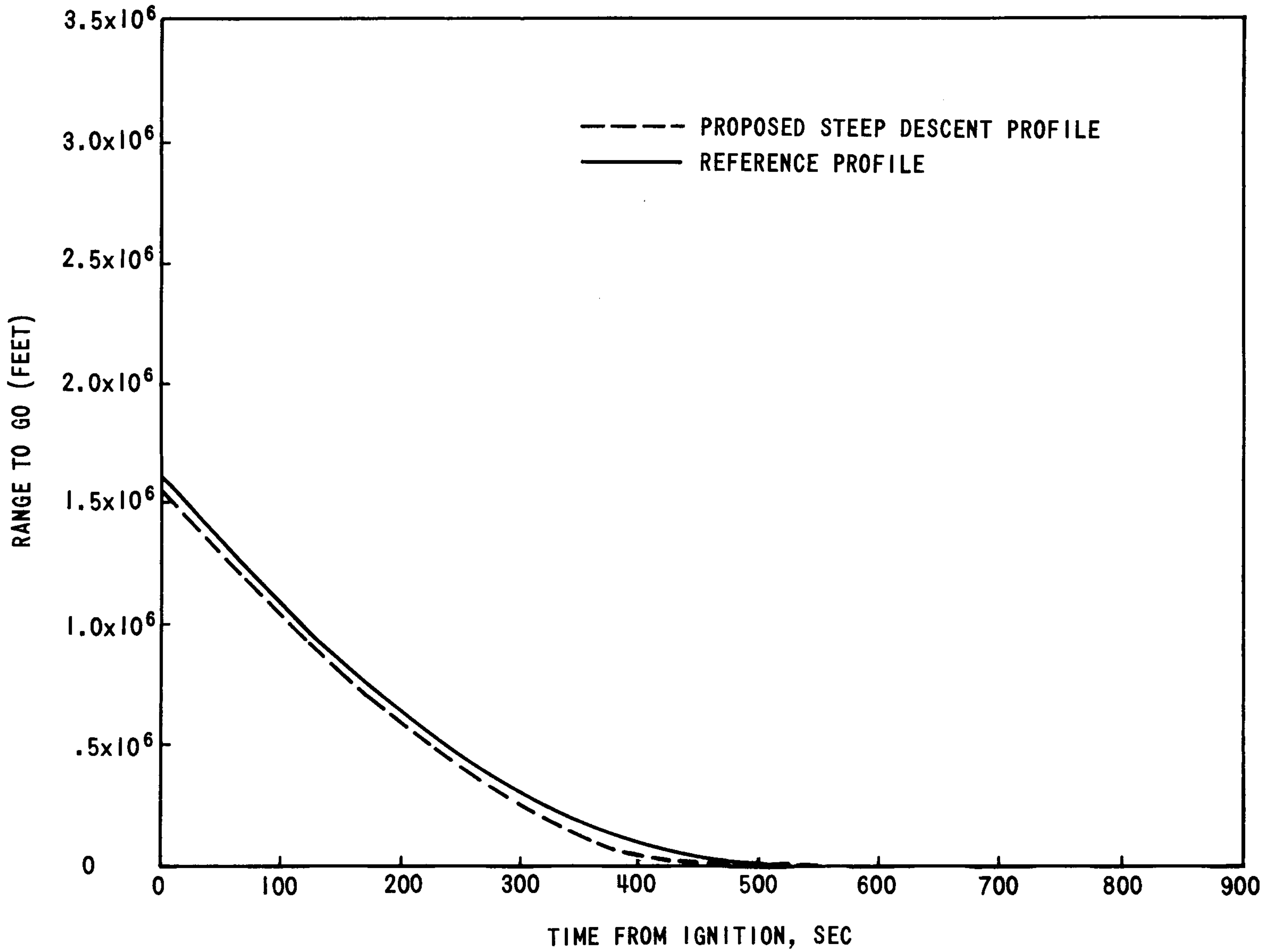

FIGURE 3a - RANGE TO GO DURING BRAKING PHASE

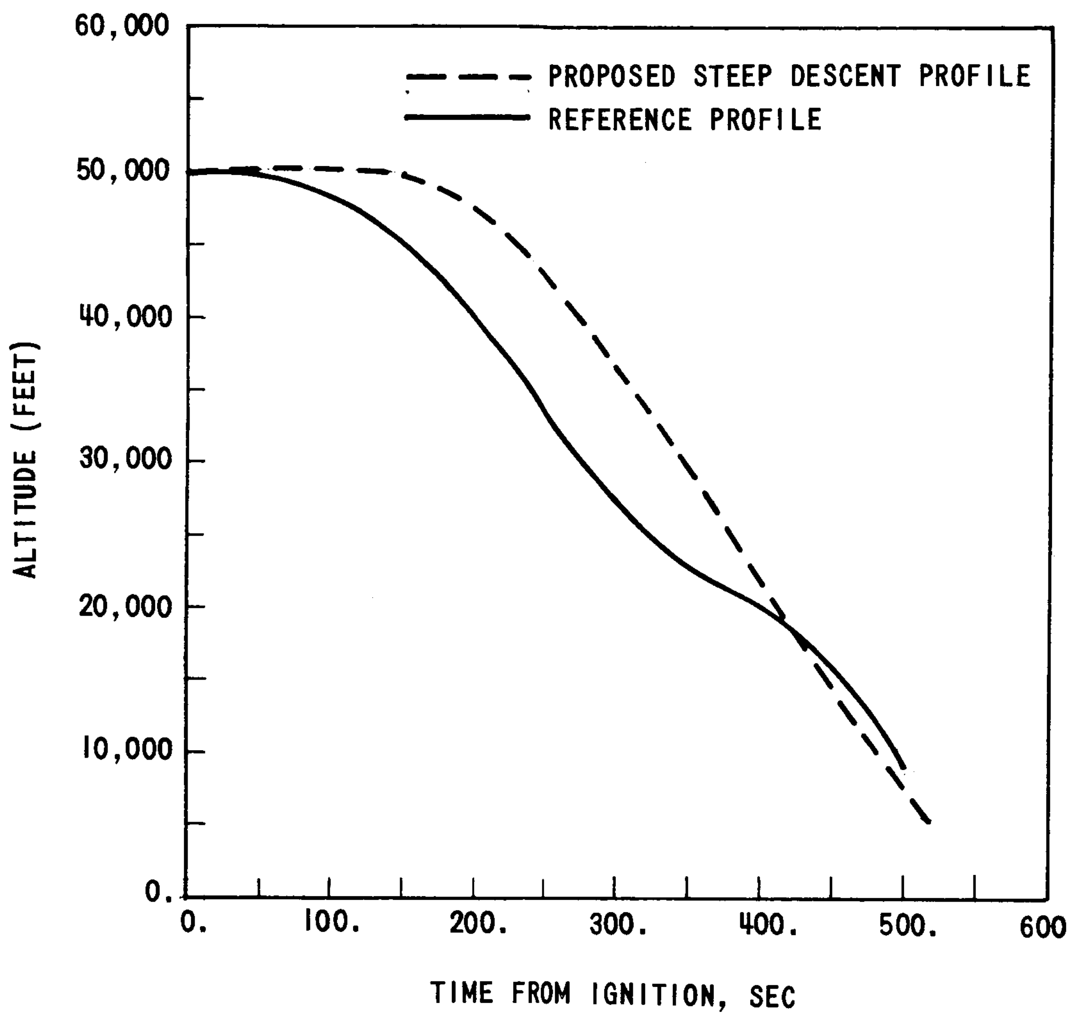

FIGURE 3b - ALTITUDE DURING BRAKING PHASE

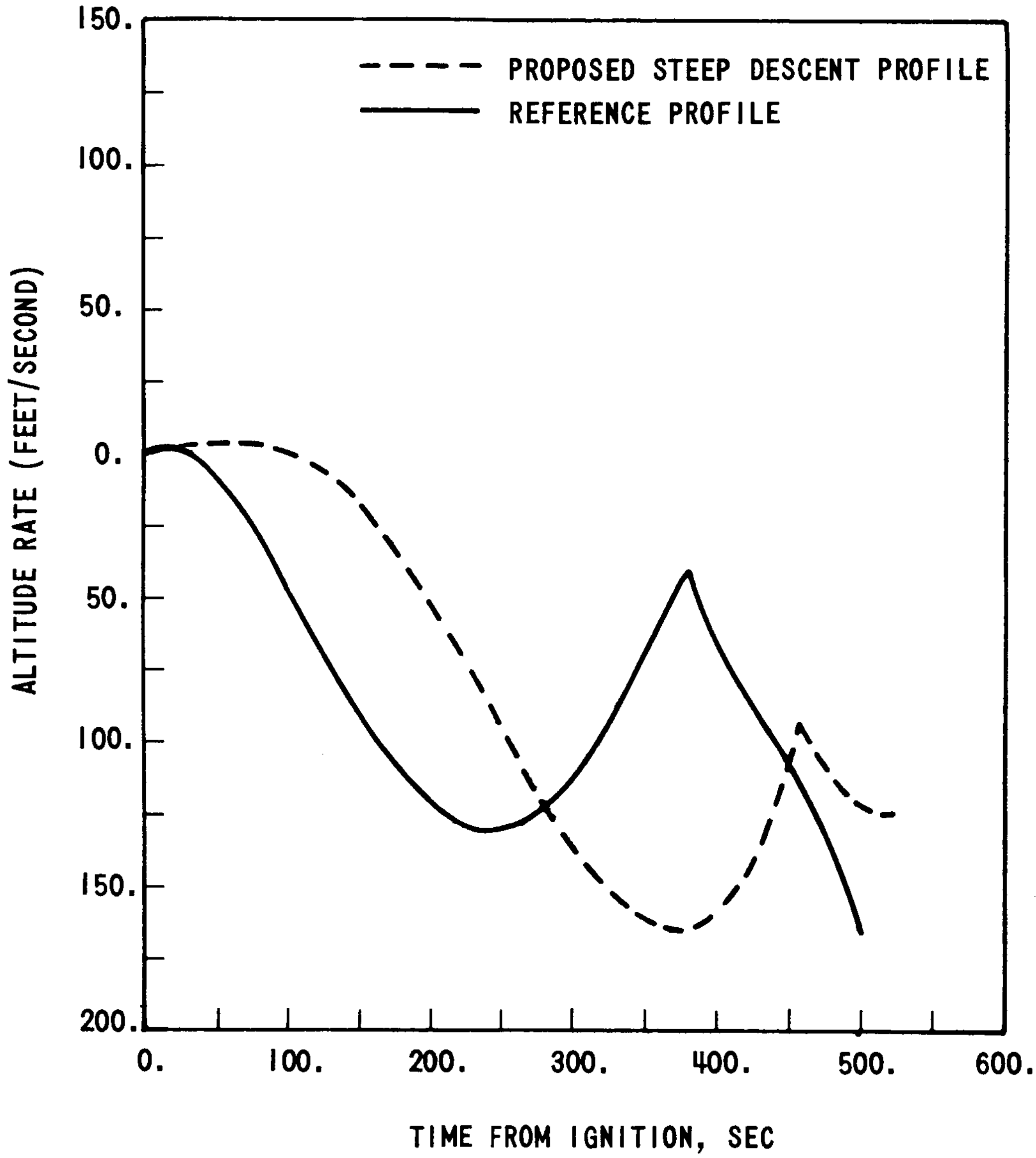

FIGURE 3c - ALTITUDE RATE DURING BRAKING PHASE

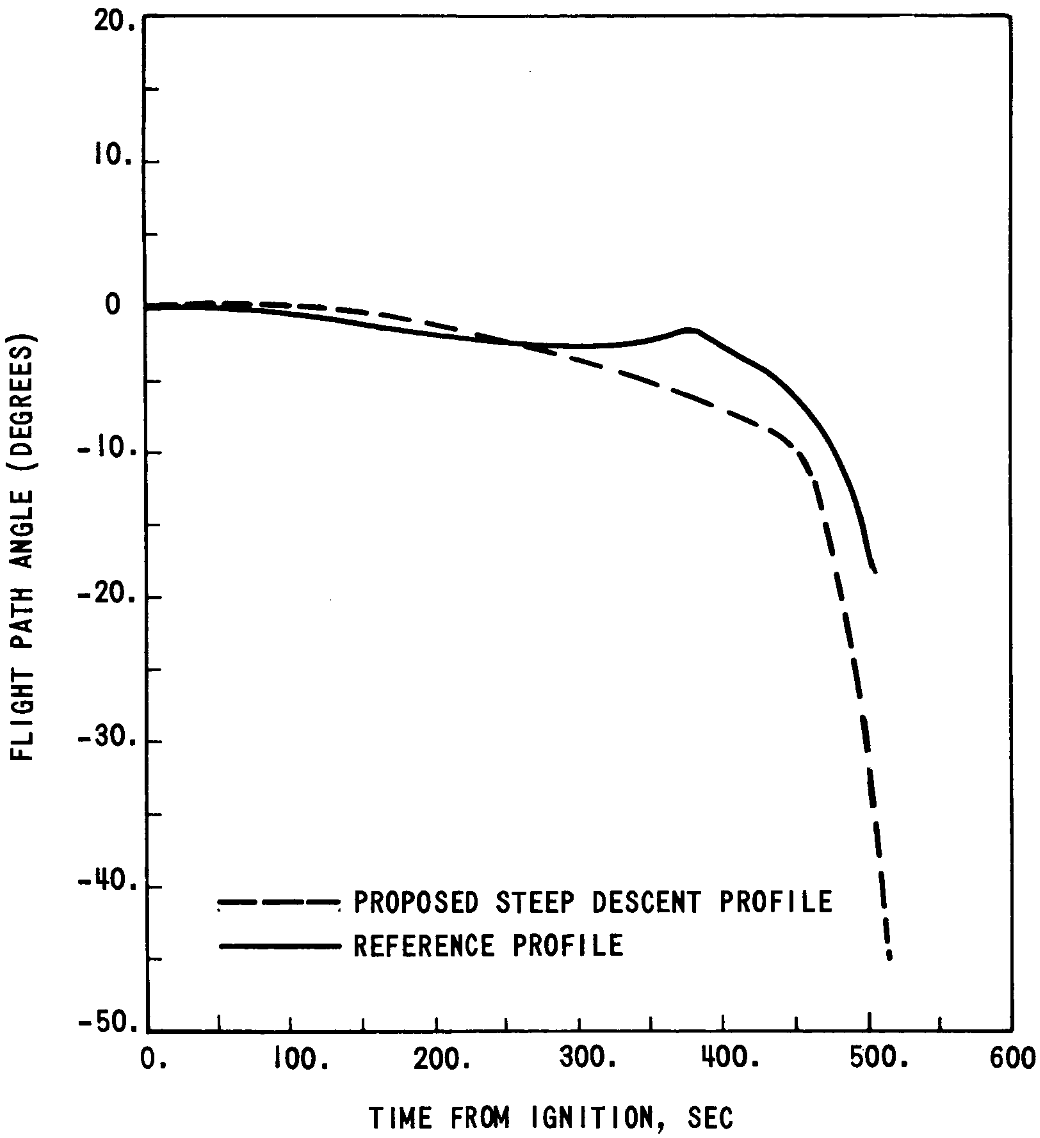

FIGURE 3d - FLIGHT PATH ANGLE DURING BRAKING PHASE

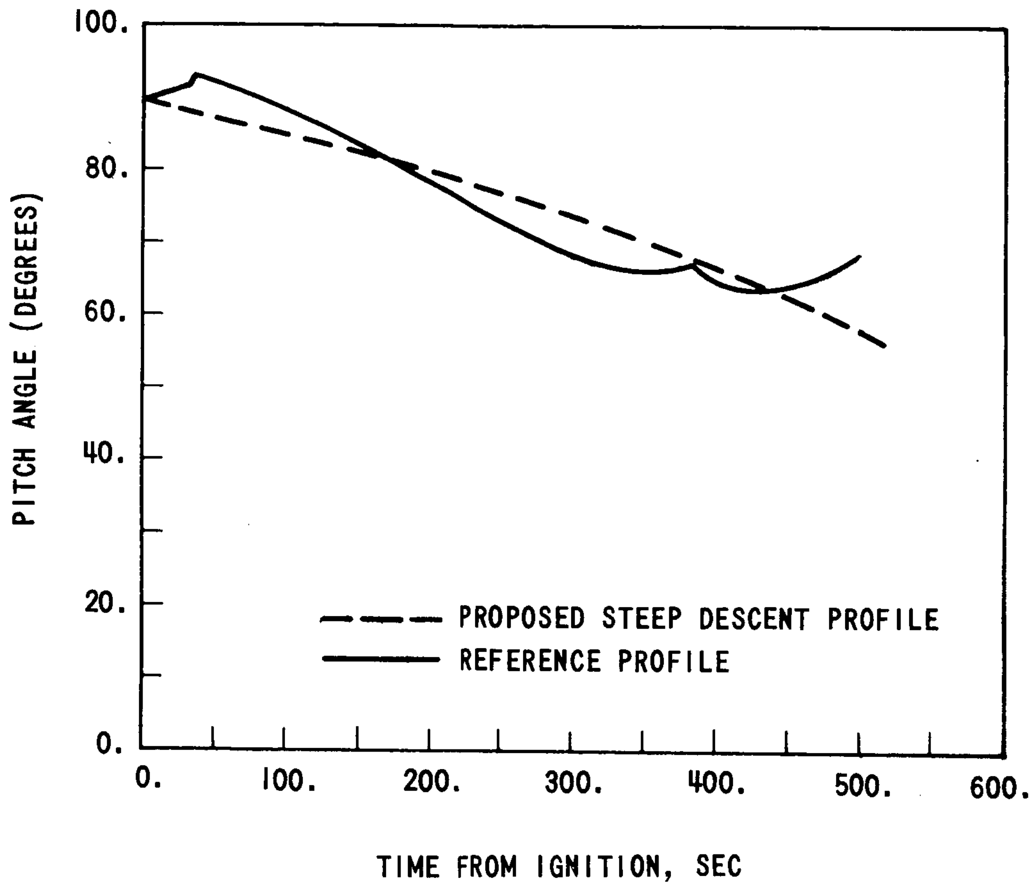

FIGURE 3e - PITCH FROM LOCAL VERTICAL DURING BRAKING PHASE

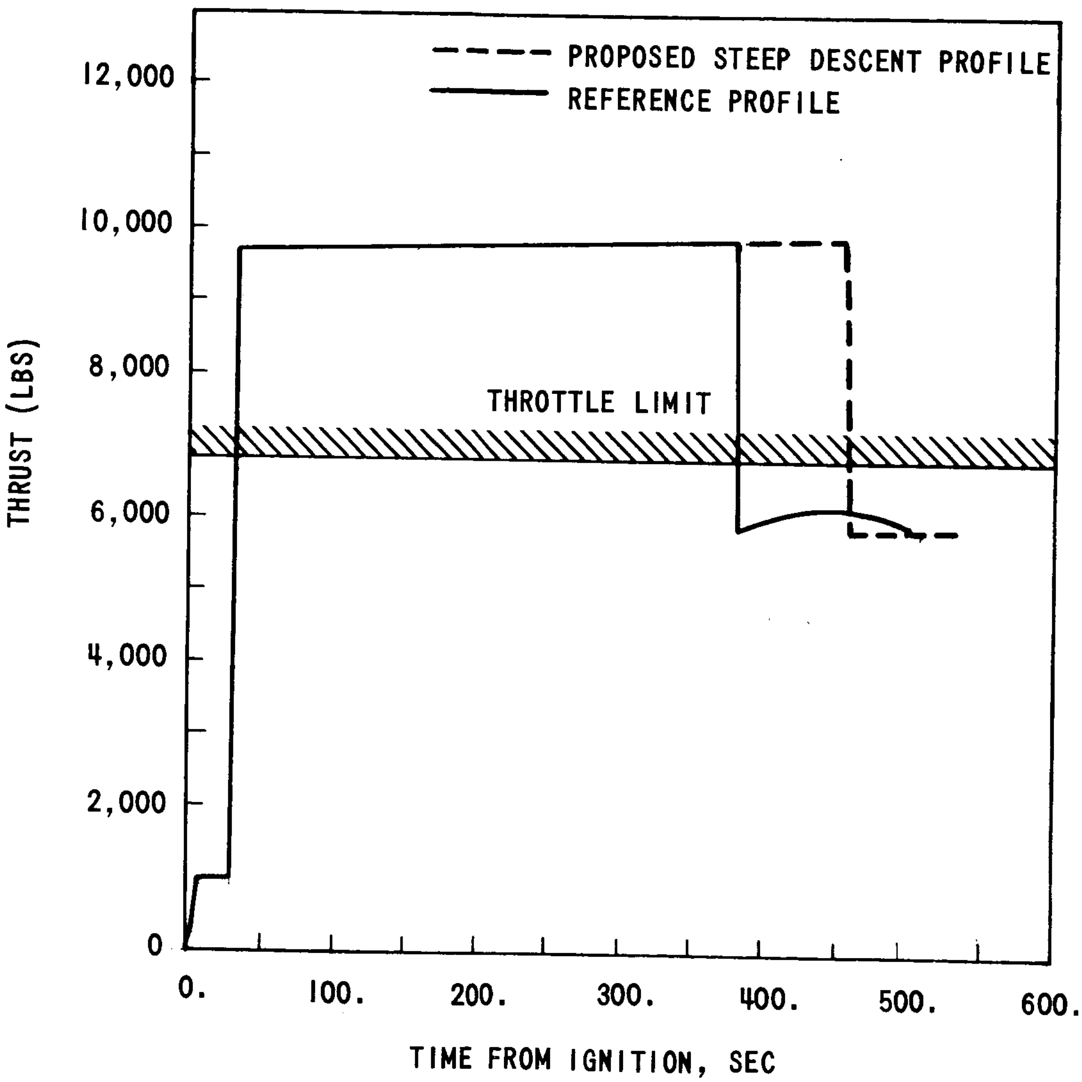

FIGURE 3f - THRUST PROFILE DURING BRAKING PHASE

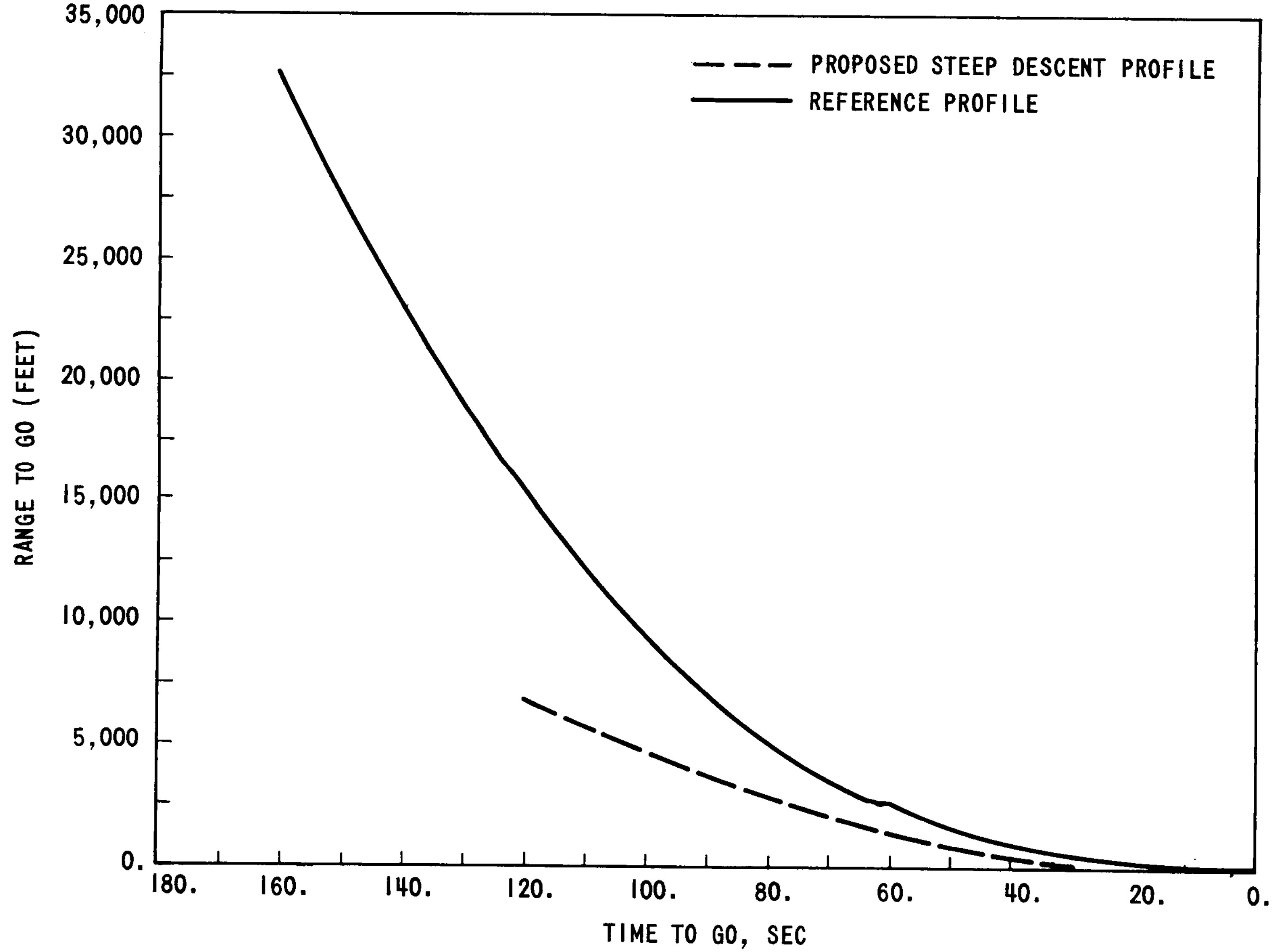

FIGURE 4a - RANGE TO GO DURING FINAL APPROACH AND LANDING PHASES.

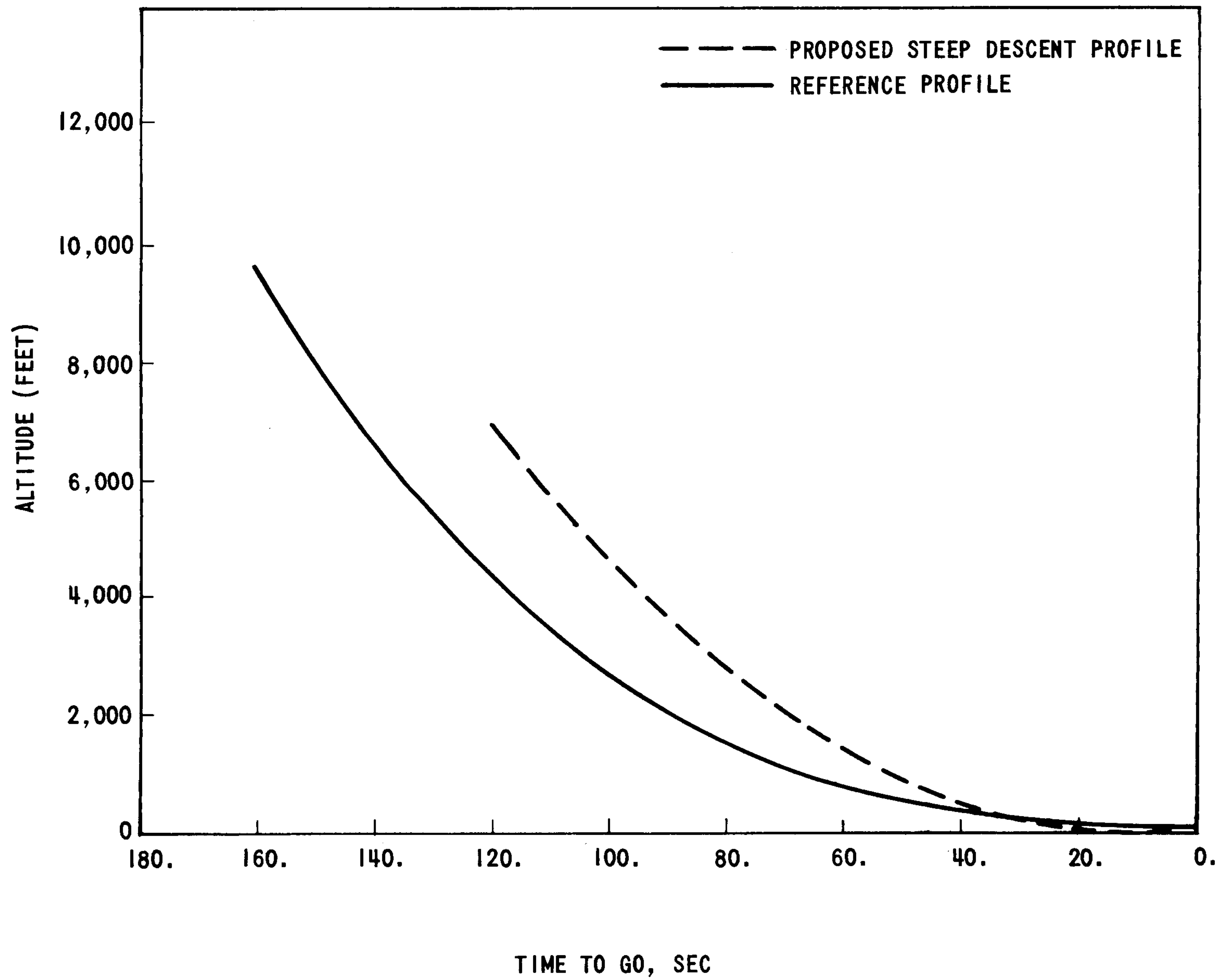

FIGURE 4b - ALTITUDE DURING FINAL APPROACH AND LANDING PHASES

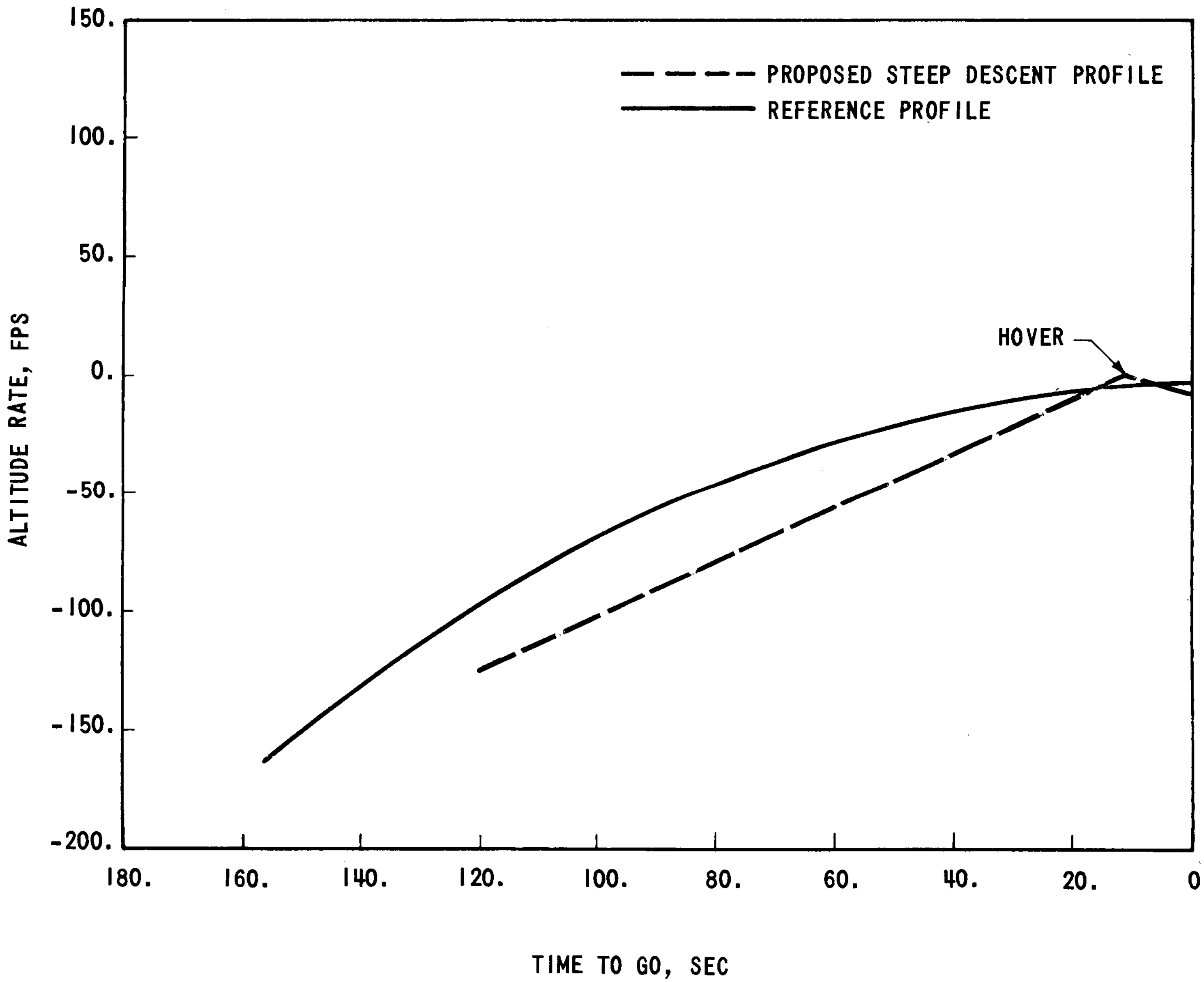

FIGURE 4c - ALTITUDE RATE DURING FINAL APPROACH AND LANDING PHASES

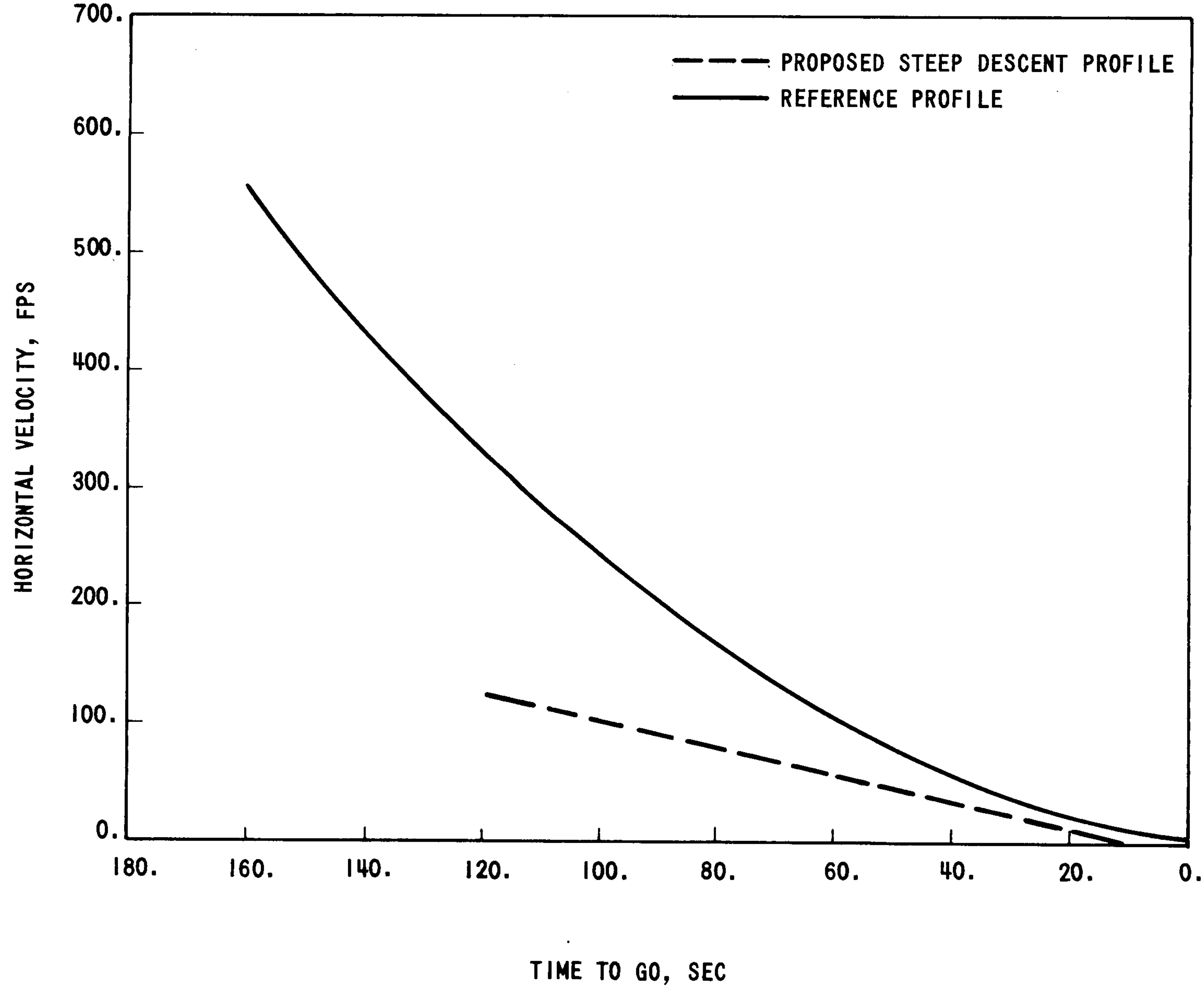

FIGURE 4d - HORIZONTAL VELOCITY DURING FINAL APPROACH AND LANDING PHASES

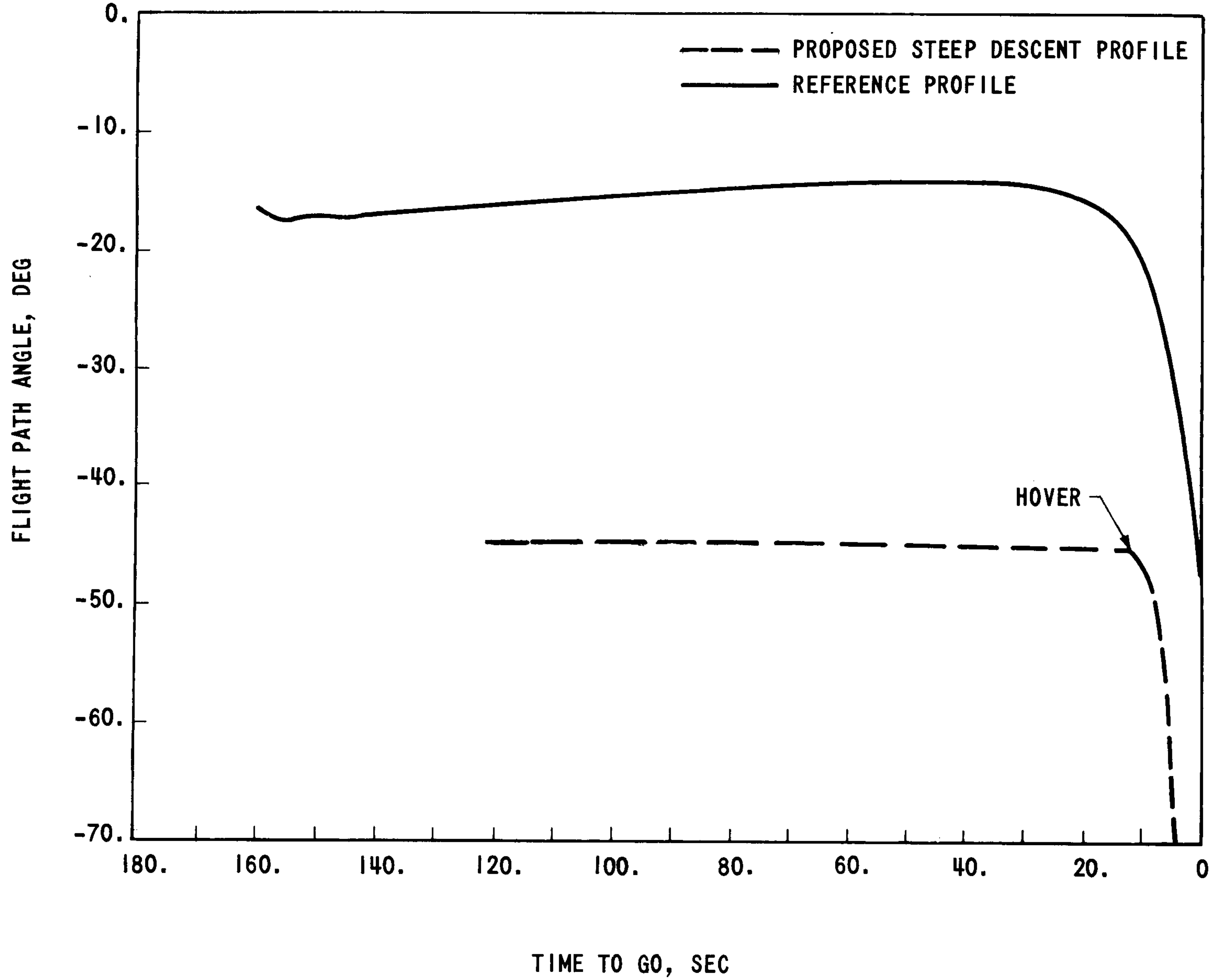

FIGURE 4e - FLIGHT PATH ANGLE DURING FINAL APPROACH AND LANDING PHASES

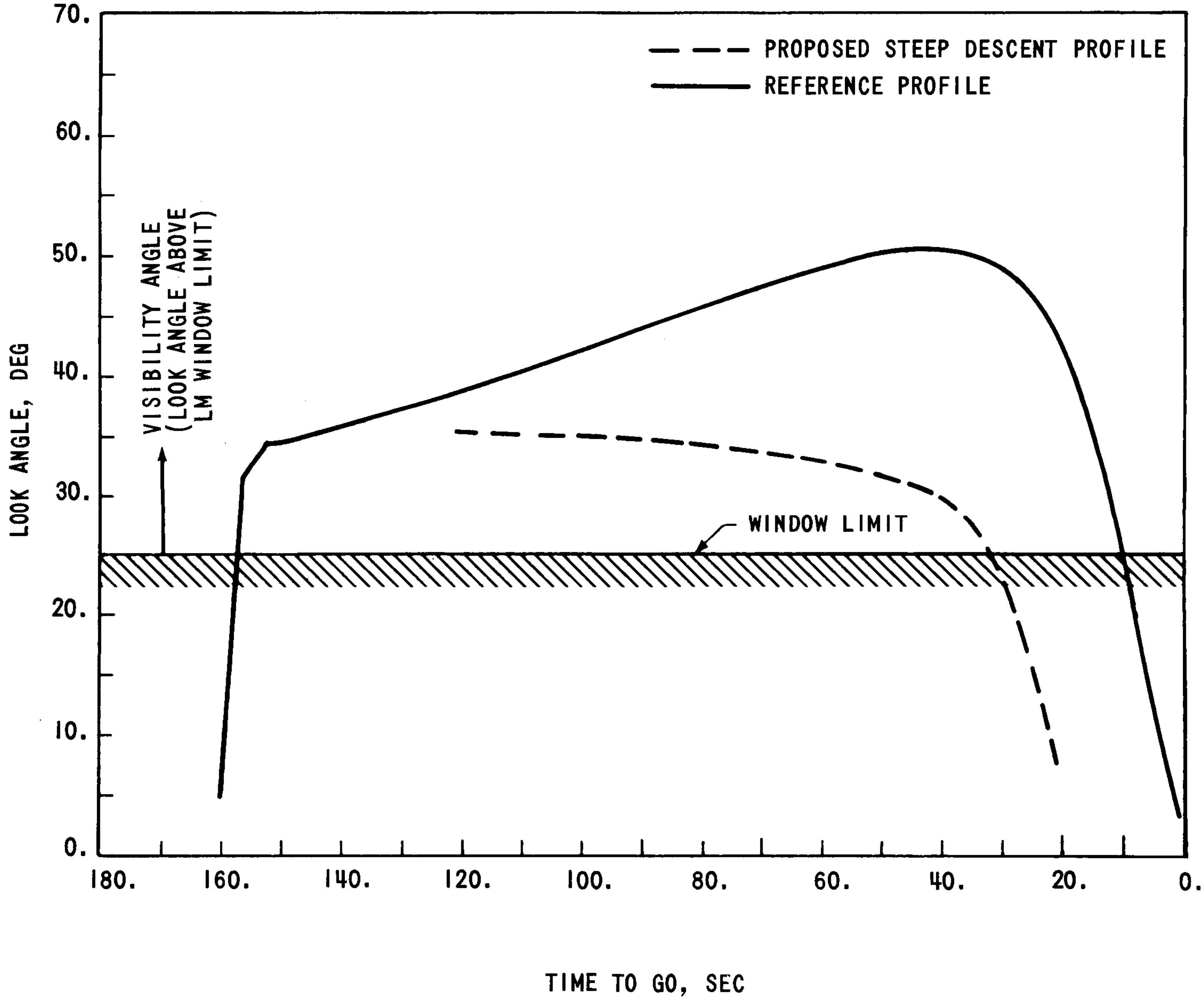

FIGURE 4f - LOOK ANGLE DURING FINAL APPROACH AND LANDING PHASES

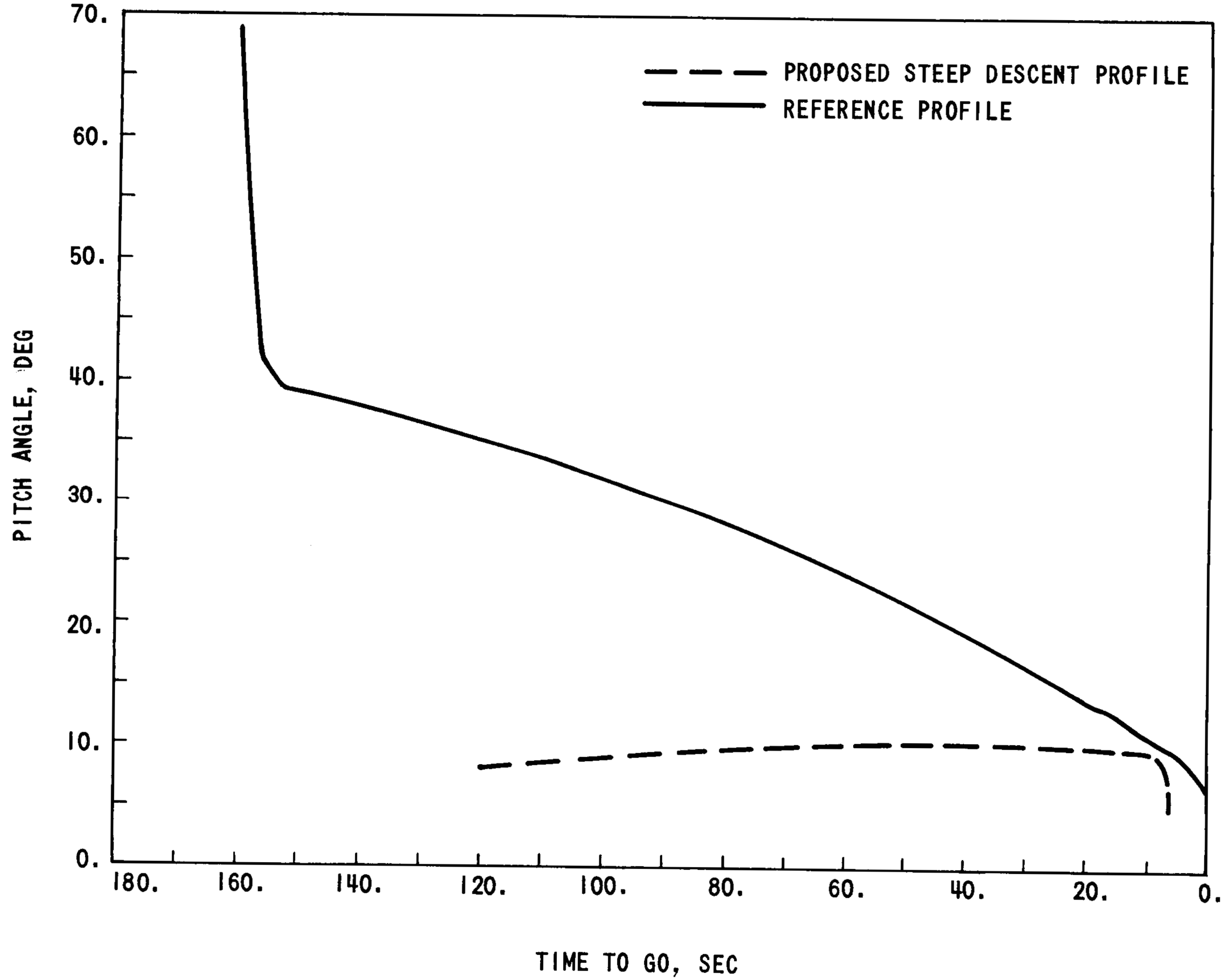

FIGURE 4g - PITCH FROM LOCAL VERTICAL DURING FINAL APPROACH AND LANDING PHASES

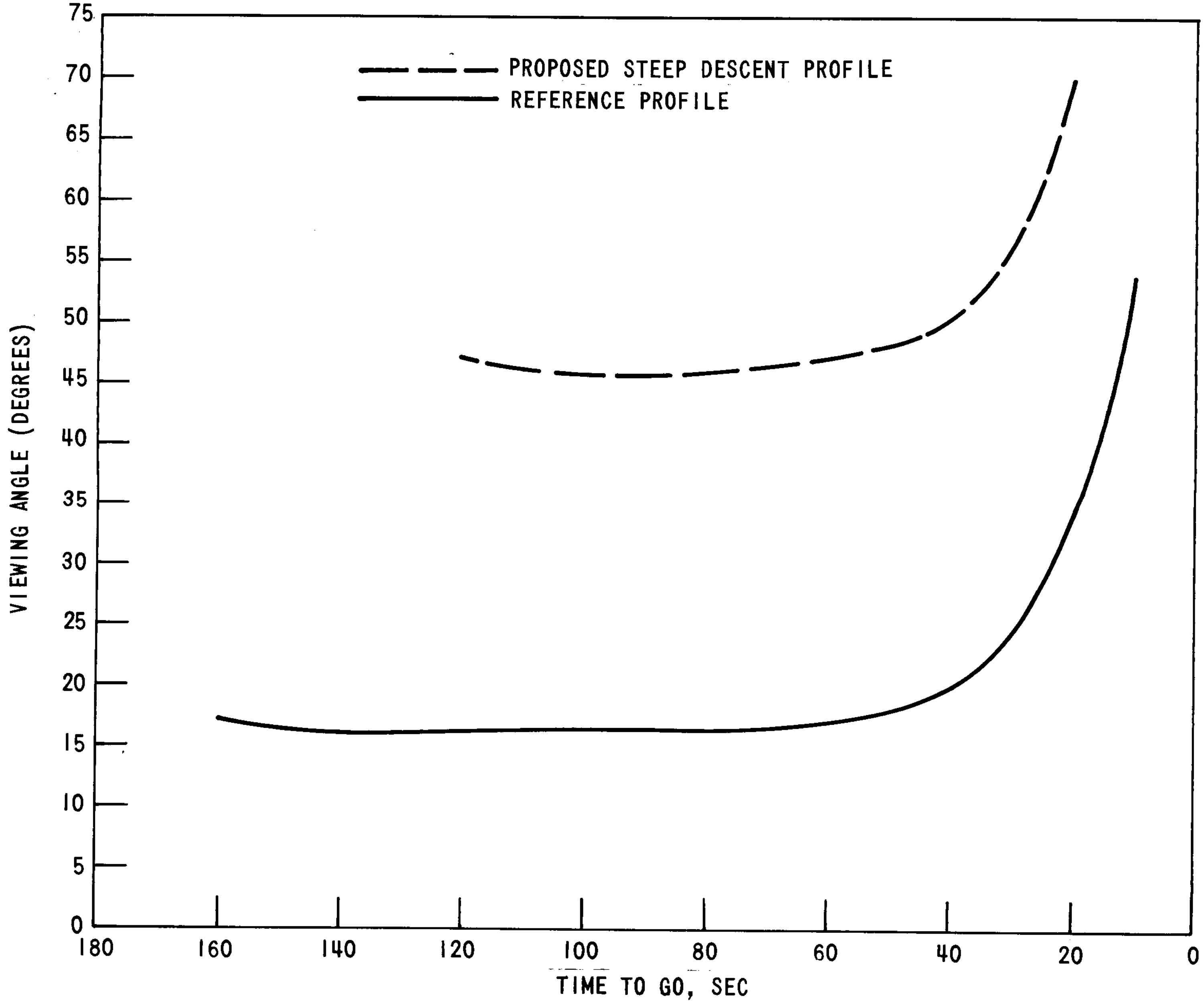

FIGURE 4h - VIEWING ANGLE FROM LOCAL HORIZONTAL DURING FINAL APPROACH AND LANDING PHASES

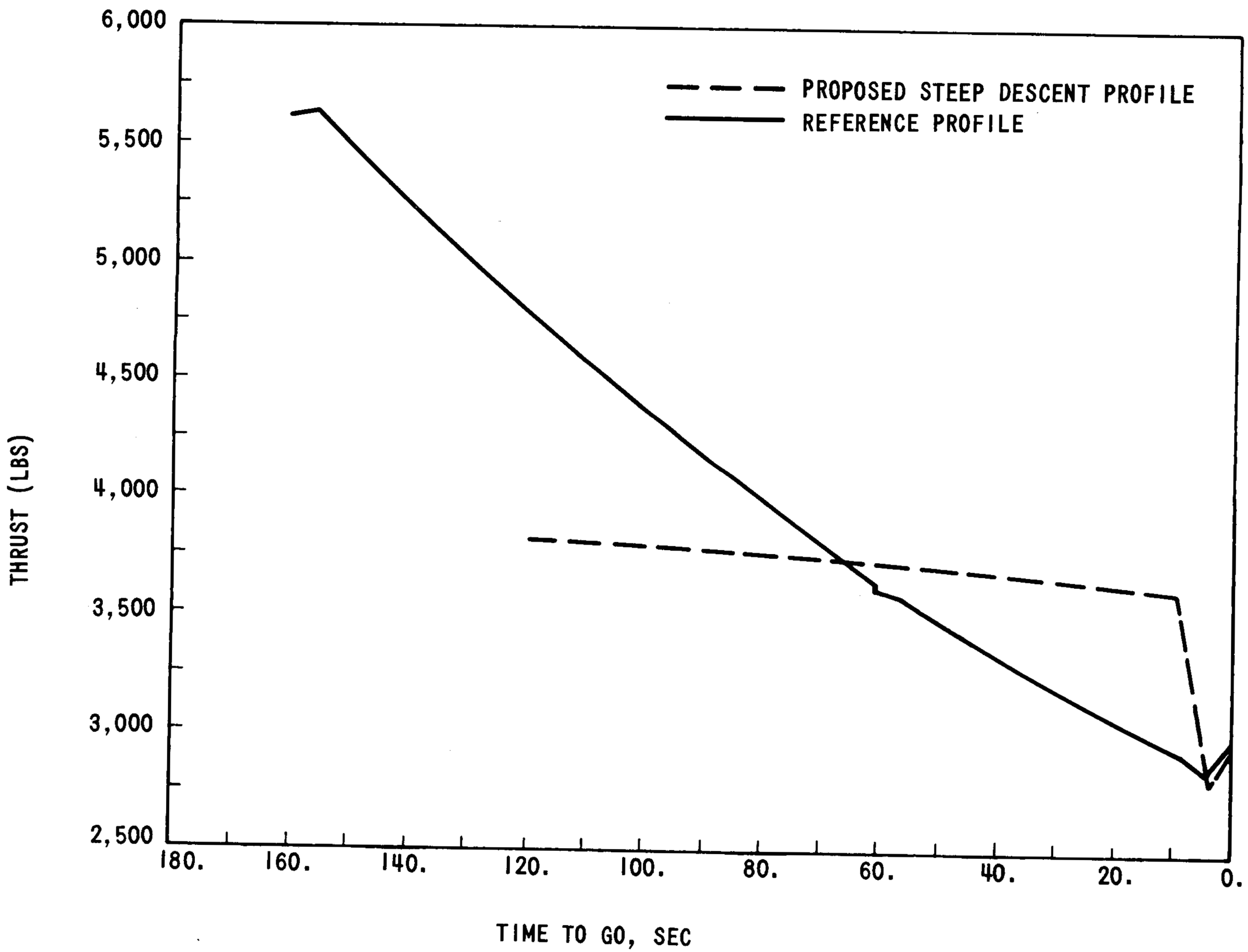

FIGURE 4i - THRUST DURING FINAL APPROACH AND LANDING PHASES

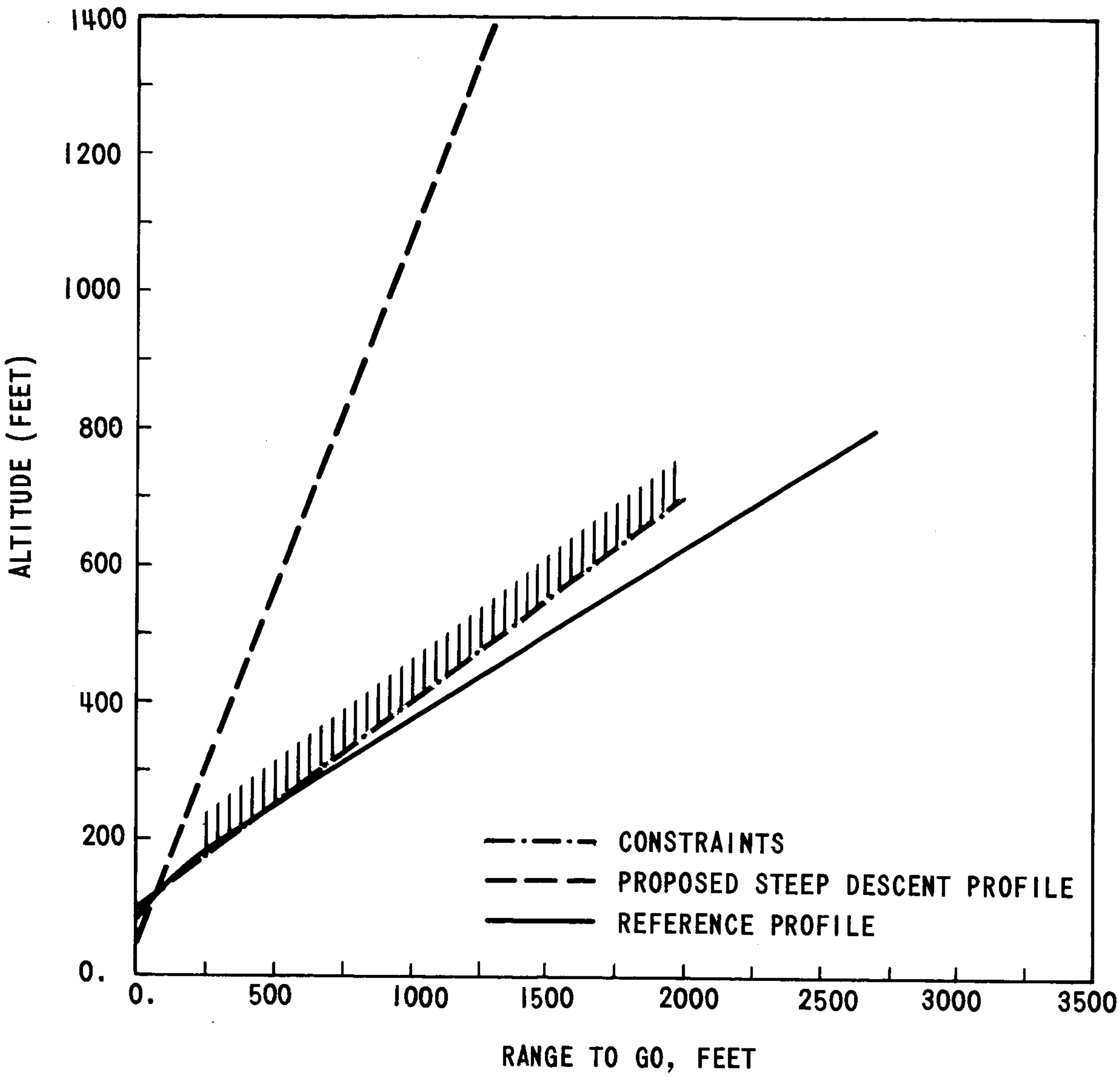

FIGURE 5a - DESCENT PHASE TRAJECTORY CHARACTERISTICS (ALTITUDE)

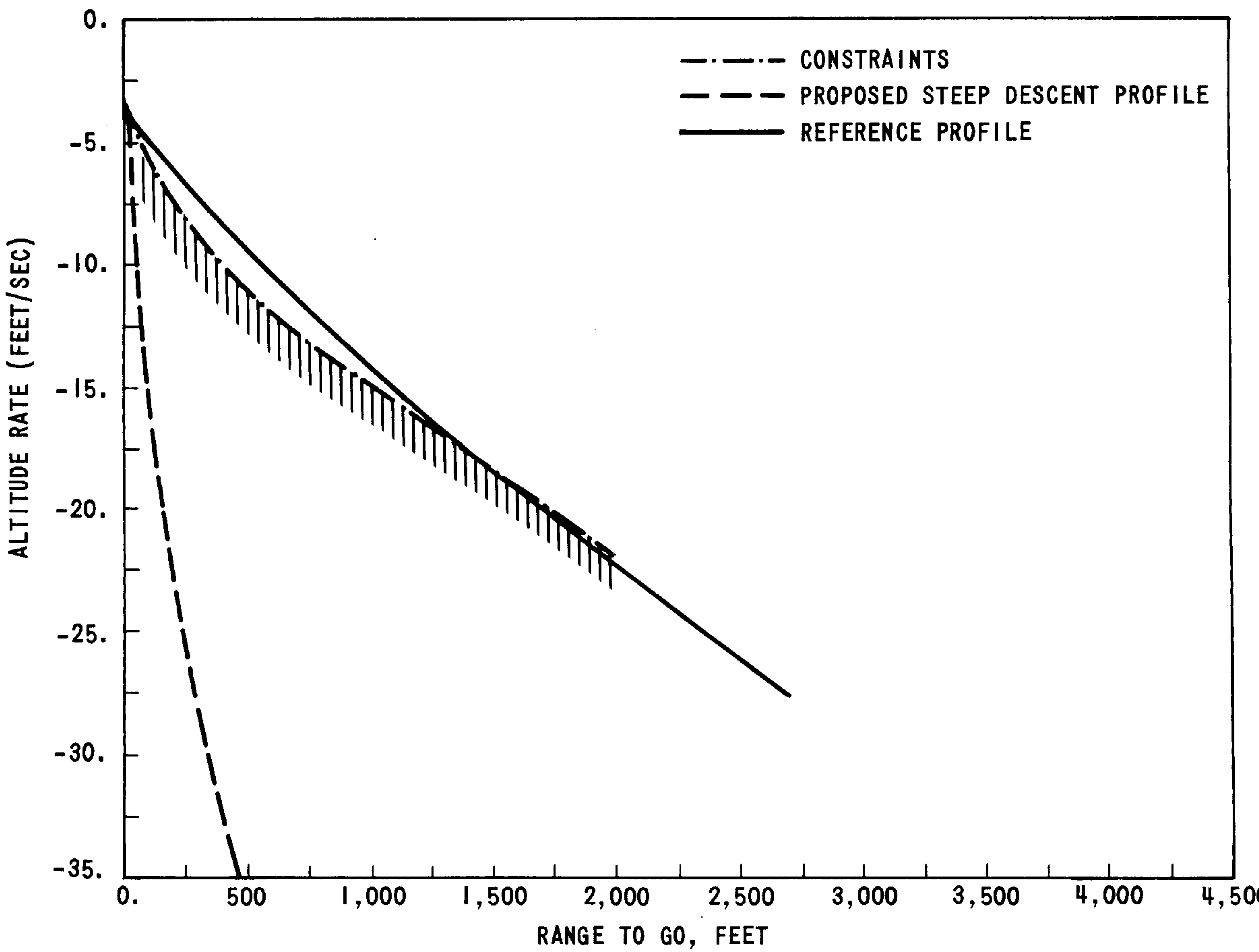

FIGURE 5b - DESCENT PHASE TRAJECTORY CHARACTERISTICS (ALTITUDE RATE)

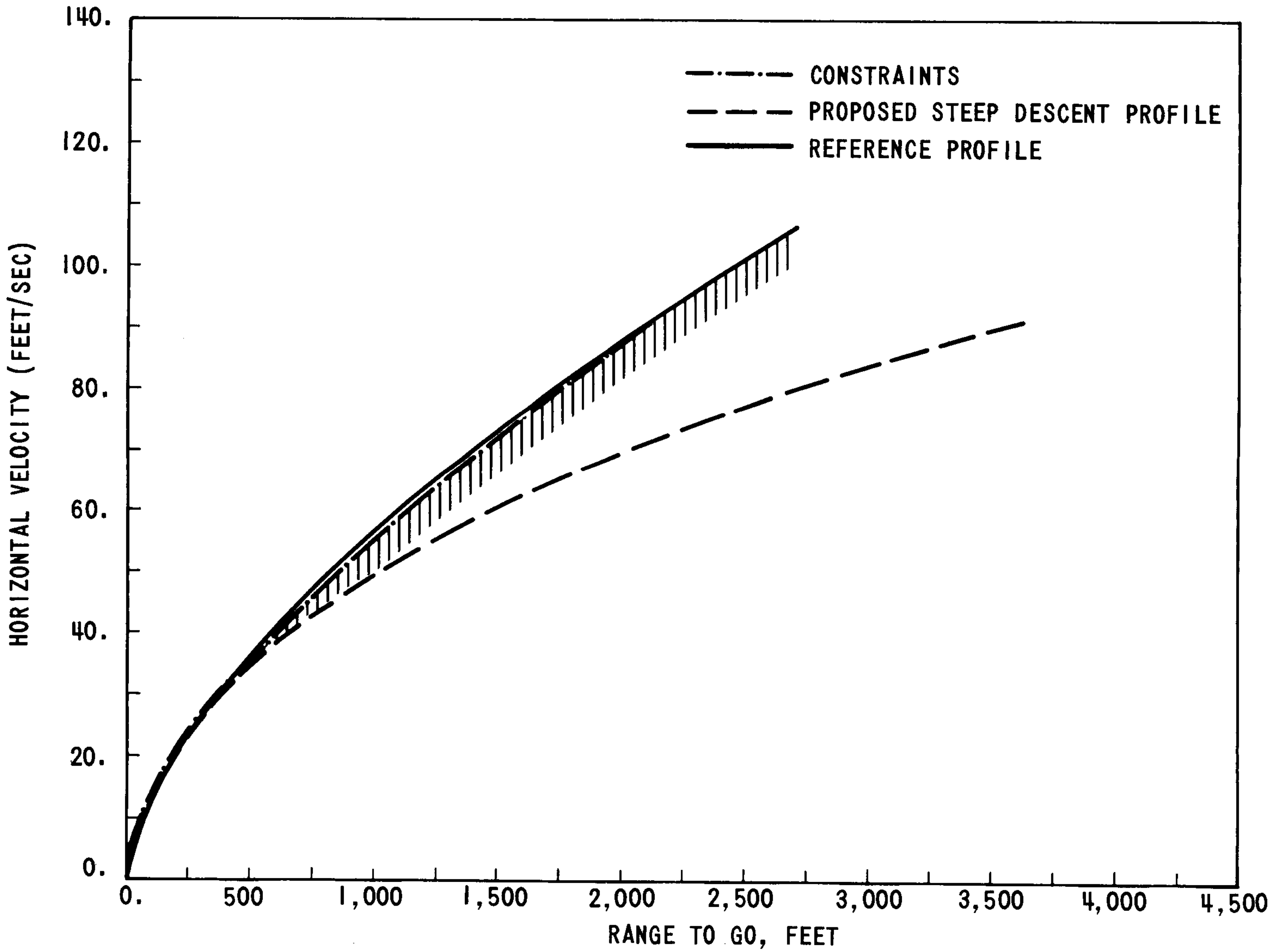

FIGURE 5c - DESCENT PHASE TRAJECTORY CHARACTERISTICS (HORIZONTAL VELOCITY)

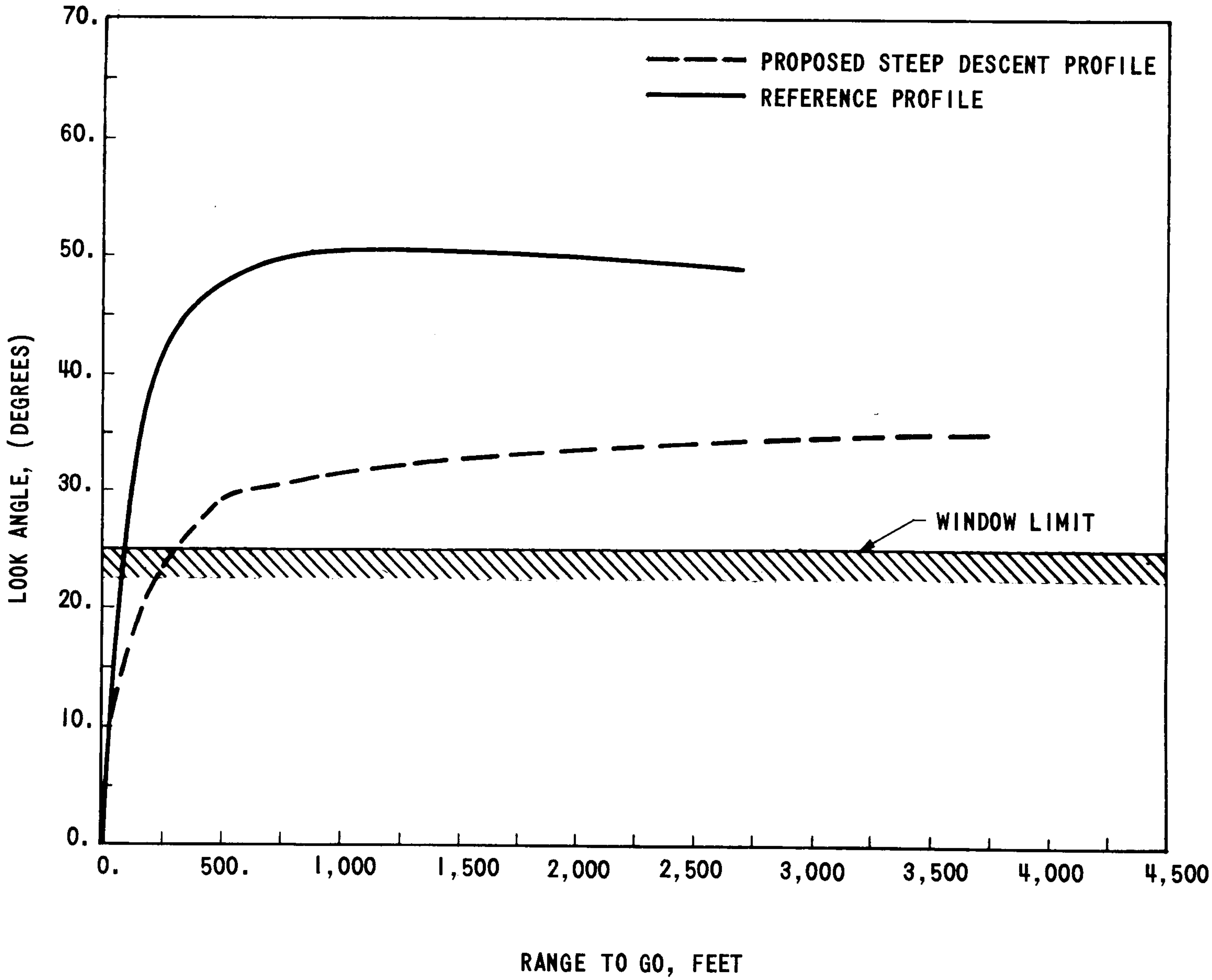

FIGURE 5d - DESCENT PHASE TRAJECTORY CHARACTERISTICS (LOOK ANGLE)

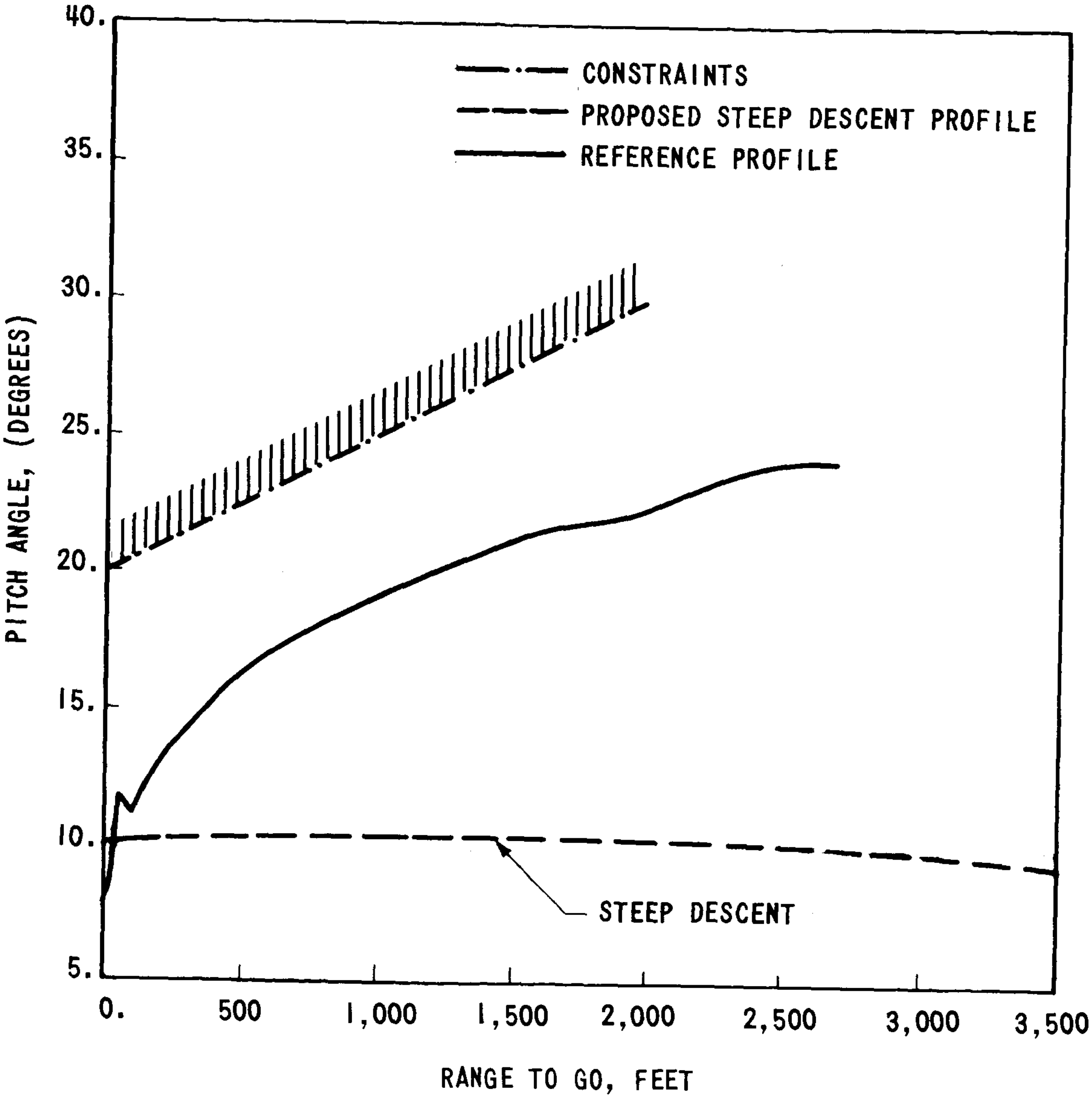

FIGURE 5e - DESCENT PHASE TRAJECTORY CHARACTERISTICS
(PITCH FROM LOCAL VERTICAL)

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